Study on Standards for Railway Electrification

prepared for
Transportation Development Centre
Transport Canada

by
Canadian Pacific
Consulting Services Ltd.

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STUDY ON STANDARDS FOR

RAILWAY ELECTRIFICATION

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prepared for

TRANSPORTATION DEVELOPMENT CENTRE

TRANSPORT CANADA

by

CANADIAN PACIFIC CONSULTING SERVICES LTD.

March 1983

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP4578E	4523	

4. Title and Subtitle	5. Report Date
Study on Standards for Railway Electrification	March 1983
	6. Performing Organization Report No.
	-

7. Author(s)	8. Transport Canada File No.
L.C. Tait, Eng. A. Gilders	D1465-317-4

9. Performing Organization Name and Address	10. DSS File No.
Canadian Pacific Consulting Services Ltd. 740 Notre Dame Street West, Suite 760 Montreal, Quebec H3C 3X6	
	11. DSS or Transport Canada Contract No. 4523

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre 1000 Sherbrooke Street West, Suite 2421 Montreal, Quebec H3A 2R3	Final, Oct. 1981 - March 1983
	14. Sponsoring Agency Code

15. Supplementary Notes	16. TDC Project Officer
	C. Alfred Versailles

17. Abstract

This report investigates two facets of electric railway operation in Canada. These are the development of suitable electrification standards and the use of salvage rail as catenary poles.

The section on standards represents a preliminary examination of the topic. To establish an information base, a literature survey was made of electrification standards observed in Britain, Denmark, France, India and Sweden. Additional sources include standards from UIC and AREA plus design proposals for constructing electrified railways. Information on the catenary, power supply and EMI was extracted and summarized. This summary is presented in a CSA standards format and can serve as a basis for more detailed discussions.

In examining the salvage rail poles, two designs by the Swedish State Railway (SJ) were looked at. These were evaluated on the basis of theoretical strength calculations. A cost summary is also included. Additional comments are made on the intrinsic factors of such poles.

18. Key Words	19. Distribution Statement
Railway Electrification Catenary Poles Standards	A limited number of copies are available from the Transportation Development Centre.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	50	-

TDC/CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. Nº du rapport Transports Canada	2. Nº de l'étude — CDT	3. Nº de catalogue du destinataire
TP4578E	4523	

4. Titre et sous-titre	5. Date du rapport
Study on Standards for Railway Electrification	mars 1983
	6. Nº du rapport de l'organisme exécutant

7. Auteur(s)	8. Nº de dossier Transports Canada
L.C. Tait, Ing. A. Gilders	D1465-317-4

9. Nom et adresse de l'organisme exécutant	10. Nº de dossier — ASC
Société d'études et de consultation de Canadien Pacifique (Ltée) 740 ouest, rue Notre-Dame, suite 760 Montréal, Québec H3C 3X6	11. Nº de contrat — ASC ou Transports Canada 4523

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transport 1000 ouest, rue Sherbrooke, suite 2421 Montréal, Québec H3A 2R3	Final, oct. 1981 - mars 1983
	14. Code de l'organisme parrain

15. Remarques additionnelles	16. Agent de projet — CDT
	C. Alfred Versailles

17. Résumé

Ce rapport étudie deux aspects de l'électrification de chemins de fer du Canada. Il s'agit de l'élaboration de normes d'électrification acceptables et de l'utilisation de rails usagés comme poteaux de catenaire.

La section sur les normes consiste en un examen préliminaire du sujet. Pour établir une banque de renseignements, nous avons procédé à une revue des articles traitant de l'électrification de chemins de fer et publiés en Grand-Britagne, au Danemark, en France, en Inde et en Suède. Les normes de l'UIC et de l'AREA, ainsi que les offres de services pour le design et la construction de chemins de fer électrifiés, constituent des sources additionnelles de renseignements. Les renseignements, touchant le caténaire, la source de puissance et l'interférence électromagetique (EMI) furent extraits et résumés. Ce résumé est présenté selon le format des normes de l'ACNOR et peut servir de base pour des discussions plus approfondies.

Pour l'utilisation de rails usagés comme poteaux, deux concepts des chemins de fer suédois (SJ) ont été étudiés. Leur évaluation a été faite sur la base de calculs théoriques de force. Une étude sommaire des coûts est jointe. Sont aussi inclus des commentaires sur les qualités intrinsèques de tels poteaux.

18. Mots-clés	19. Diffusion
Electrification ferroviaire Caténaire Poteaux Normes d'électrification	Le Centre de développement des transport dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Aucune	Aucune	50	-

CDT TDC 79-005

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1. INTRODUCTION

The use of railway electrification in North America has largely been confined to passenger service. In contrast to this diesel locomotives have been the dominant source of traction for the freight and raw material payloads commonly found in the North American environment. Electrification has had little impact in this area.

However, the situation may be changing. The price and supply of liquid fuels have undergone dramatic changes in the past decade. In the same period, railway electrification has benefited from new technological designs such as the use of thyristors for rectification and motor control. These are two of many factors which have raised the possibilities of more extensive use of electrification.

As with the adoption of any new technology, the switch to electrification will bring in its own construction and operating practices. Though these practices may be new and unfamiliar in the Canadian context, they have been well tested on a global basis. Canada could benefit from such past experience with electrification, particularly from areas, such as Sweden, which have climates similar to that found in North America.

The ultimate purpose of which this report is one step is to provide this information in the form of a Canadian railway electrification standard. This document would require extensive investigation of all facets of electrification. By undertaking this task, however, a standard would not only expand a railway's knowledge of practices associated with a safe and reliable electrified operation, but it would also outline the implications of electrification for concerned secondary parties. This latter group represents those companies which are not involved directly with transportation but would be hindered in their operation by the presence of an electrified line.

A prime example of this is the needed coordination between railways and electric utilities. Electric railways could present a problem for utilities in the forms of unbalanced loads and harmonic generators.

Standards would be required to determine the responsibility of the railways and utilities in each area.

A second example is the effects of electro-magnetic interference (EMI). Electric railways also represent a source of EMI which can interfere with local communication networks or track side communications. The reconditioning of such facilities to mitigate EMI can represent a major expense to the railway and/or affected party. Thus it warrants mention within the standard to set a reasonable limit of generated EMI, techniques to reduce EMI, and how these responsibilities are to be divided.

The issue of EMI also raises the question of public safety. Off-track structures can be energized by electrostatic coupling with the high voltage catenary. These can represent public safety hazards if they are not properly grounded. Guidelines are required which would limit the accessibility of such structures plus high voltage equipment and lines to non-trained personnel.

The above examples give an indication of how wide-ranged and complex the issues can be. This report will begin to discuss establishing a Canadian electric railway standard. As indicated earlier, this report begins by examining practices and standards observed in other countries.

A second part of this part investigates the use of salvage rail as a catenary mast. This idea was proposed as a possible means to offset some of the high initial costs of electrification. If otherwise acceptable, salvage rail could provide a plentiful supply for catenary poles. Two designs submitted by the Swedish State Railway (SJ) were evaluated with respect to strength, costs, and appearance.

2. ELECTRIFICATION STANDARD

2.1 General

Appendix A gives a summary of construction and design practices associated with electric railways. The information base for this summary was established by a literature search of national standards. Particular importance was placed on data that would apply in the Canadian environment and that would be useful in establishing Canadian standards.

2.2 Format

The summary is written in a proposed railway electrification standard format. This format is that used by CSA in its standards. The first section consists of the documents scope. Definitions of technical terms follow in the second category. The remainder of the report is divided into sections and sub-sections that deal with the technical specifications. In Appendix A, section numbering was based on depth of coverage. Thus topics covered in greater detail were placed ahead of those which were mentioned briefly.

2.3 Subject Range

Because of the extensive subject range, only two topics were examined extensively. These are catenary vertical and lateral clearances. Also discussed, but in lesser detail, were:

i) Catenary Construction
ii) Power Supply
iii) Electro-magnetic interference (EMI).

Some sections are mentioned by title only. These areas were not examined in this report but are cited as topics for further discussion.

Only 25 and 50 kV systems were considered.

2.4 Information Sources

Information sources for the summary include national railway standards observed in Britain, France, Denmark, India and Sweden. The following railroad electrification studies were also used:

i) BCR TUMBLER RIDGE BRANCH LINE STUDY;

ii) ELECTRIFICATION DEMONSTRATION PROJECT WITH THE CARTIER RAILWAY COMPANY.

These two studies cover electrification projects in Canada. International specifications determined by UIC and AREA complete the list of sources. A more detailed description is given in the bibliography.

3. SALVAGE RAIL DESIGN

3.1 Design Description

This portion of the report examines the use of salvage rail as catenary poles. Two designs were submitted by SJ for evaluation. One construction consists of two rails bolted together at the base (see fig. #1). The other design joins the rails crown to crown through the use of fishplates (see fig. #2). The second design was considered as it offers advantages in cantilever mounting and stiffness of footing.

3.2 Strength Calculations

Theoretical strength calculations for the two designs are given in Appendix B. The results are summarized as follows:

i) The stress limitation of the rail does not govern in the design;

ii) The perpendicular track deflection is approximately 61 mm at the top of the pole (no cooperation between rails);

iii) Perpendicular track deflection for design I (crown to crown) is 32 mm (cooperation between rails);

iv) Perpendicular track deflection for design II (base to base) is 21 mm (cooperation between rails).

These calculations assume 132 lb/yard (65.48 kg/m) rails with catenary and loads of 1700N, 1500N and 1800N acting at 9.3 m, 8.1 m and 7.2 m respectively.

3.3 Cost Summary

The following cost estimate of the two designs was obtained from the Quebec Cartier Mining Company who fabricated the poles.

Design I:

Material:	$462
Labour:	$457
Total:	$919/pole

Design II:

Material:	$332
Labour:	$657
Total:	$989/pole

Prices quoted are in Canadian dollars.

3.4 Appearance

There are a few drawbacks to the use of salvage rail as catenary poles. As this design is not a standard configuration, many of the brackets and fittings for the cantilever are not suitable. It is expected that new models must be designed and manufactured. Scrap poles are very heavy and more awkward to handle than fabricated or wood poles. This would be a factor when rail access time for catenary construction is limited. It is also costly to transport these poles to construction site. Finally, the aesthetic appearance of scrap rail poles does not compare favourably to some of the newer designs used in Europe.

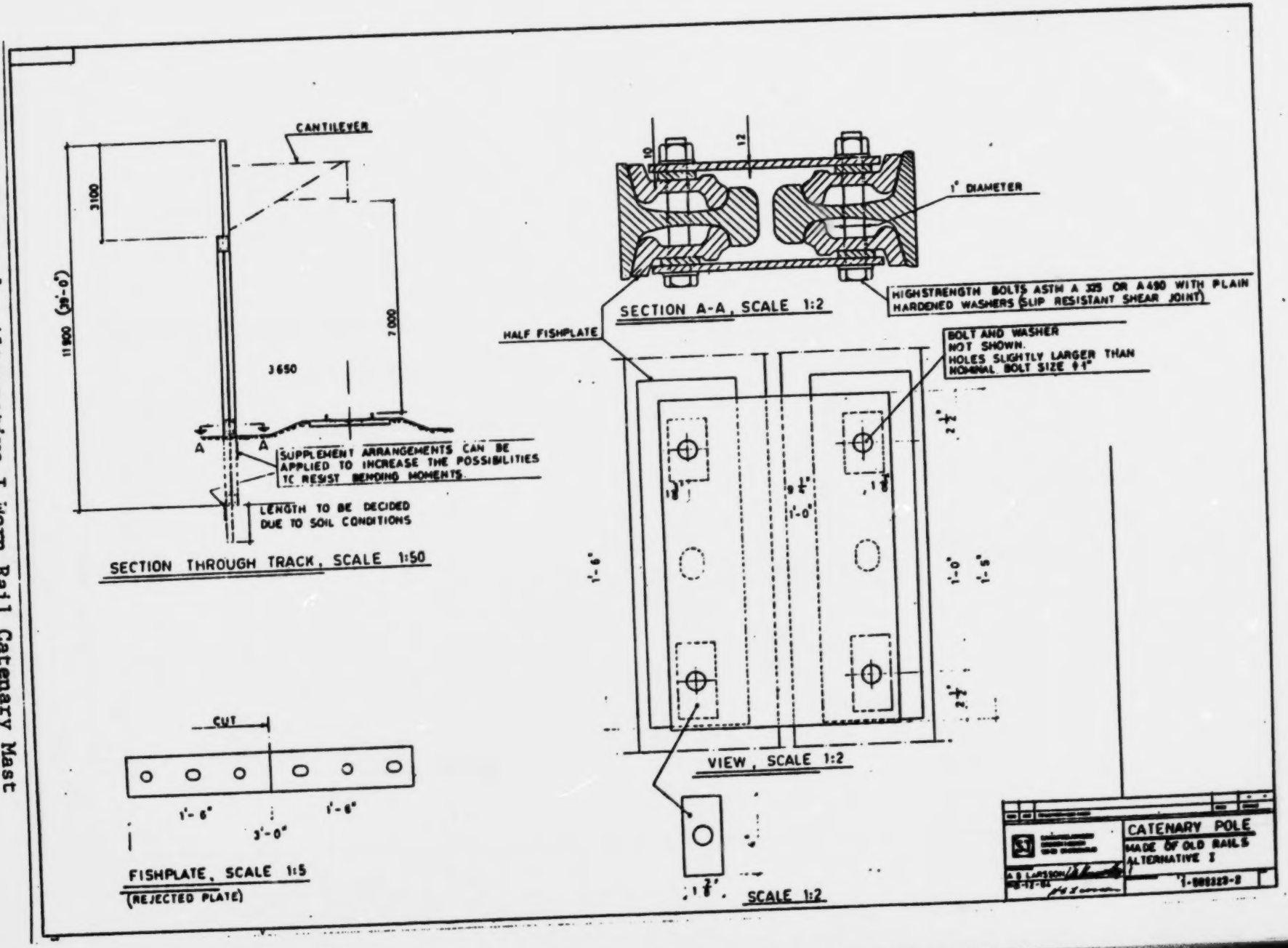
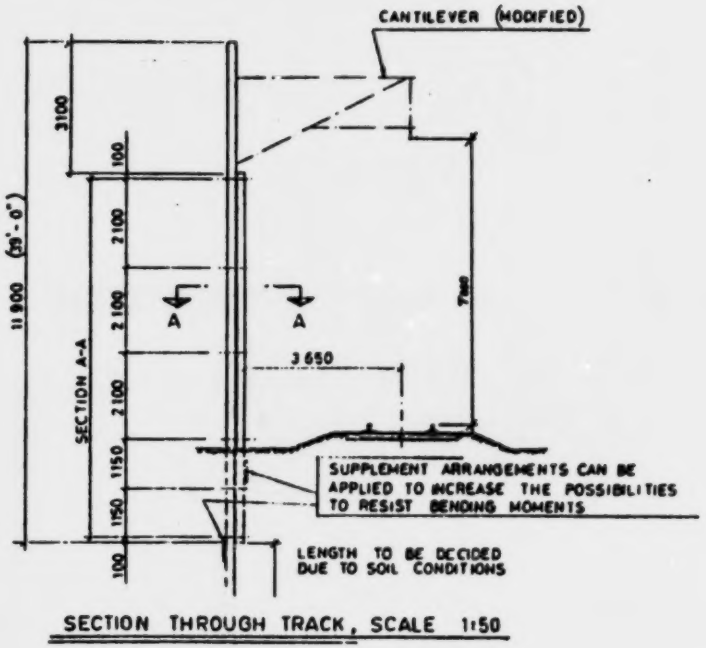
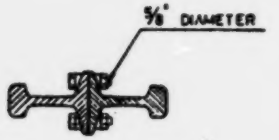


Figure 1. Alternative I Worn Rail Catenary Mast



SECTION THROUGH TRACK, SCALE 1:50



SECTION A-A, SCALE 1:5

CATENARY POLE
MADE OF OLD RAILS
ALTERNATIVE II

A B LARSSON 88-12-04

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Figure 2. Alternative II Worn Rail Catenary Mast

APPENDIX A

EXAMPLE OF A

CANADIAN RAILWAY ELECTRIFICATION STANDARD

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1. SCOPE

This document is a summary of some existing railway electrification practices which may be applicable to Canadian railways. As such, it can serve as an information base for establishing a Canadian railway electrification standard. Foreign standards and two studies on Canadian electrification projects were the principal sources of information. This summary concentrates on the physical construction and design parameters of the catenary, power supply and track side communications. Other areas such as maintenance, operating practices and personnel safety are left for future discussion.

2. DEFINITIONS

Ampacity: the current carrying capability of a wire.

Annealing: a process involving heating and cooling which results in softening of the metal.

Arcing: see Flashover.

Blow-off: deviation of contact wire due to a lateral wind load.

Bonding: electrical connection between two conductors.

Catenary (system): general term referring to all the components of the overhead system. Includes messenger, contact and return wires, masts, and tensioning equipment.

Contact wire: wire which makes contact with pantograph. Also known as trolley wire.

Coupling: refers to the manner in which energy is transferred from a source to a receiver.

Dynamic Conditions: the state of the catenary as it moves due to pantograph uplift.

Electrical Clearances: the necessary separation between a live component and a structure to prevent flashover.

Flashover: the «jumping» of current flow as the connection between two conductors is broken. Often associated with poor pantograph and contact wire connection.

Ground Currents: currents that result because of a voltage difference between two or more grounds joined together.

Impedance Bonds: bonds designed to conduct traction return current and act as a high impedance to AC track current signals.

Load Gauge: the maximum height of a load or railcar allowed on a railway.

Radial Ice Load: load increase on the catenary created by a cylindrical coating of ice.

Regulating Equipment: equipment designed to maintain constant tension in the catenary wires. Also known as constant tensioning devices.

Single Rail Track Circuits: track where only one rail carries the traction current.

Stagger: the offset of the contact wire at a support.

Static Conditions: the catenary in normal position (i.e. without locomotive operation).

Tension Section: length of catenary with constant tensioning units at both ends.

Trolley Wire: see contact wire.

3. CLEARANCES

3.1 SCOPE

Clause 3 covers vertical and lateral clearances between the catenary and surrounding structures. Electrical clearance figures were taken as minimum values under dynamic conditions. As a result, the total vertical and horizontal clearances are minimum values. A brief examination is also made of the effects of ice and wind loadings in the Canadian climate.

3.2 VERTICAL CLEARANCES

Figure A-1 illustrates a typical vertical catenary profile subdivided into clearance sections. Table A-1 lists the dimensions for each section based on the given sources. From this table, the following were noted:

(A) The choice of higher voltage supply will result in the need for greater clearances, both vertical and lateral.

(B) 3 classifications for vertical clearances of 25 kV have been adopted in some cases. They are:

(1) Normal clearances: 200 mm for electrical clearance and 75 mm tolerance for contact wire height.

(2) Reduced clearances: 150 mm for electrical clearance and 10 mm tolerance for contact wire height.

(3) Special reduced clearances (requires special approval): 70 mm for electrical clearance and $\pm$ 10 mm tolerance for contact wire height. Generally used in areas of difficult or expensive design.

(C) Varying load gauge and track tolerance account for most of the difference in the catenary height between railways which operate at a common voltage level.

Figure A-1 - Vertical Clearances

VERTICAL PROFILE

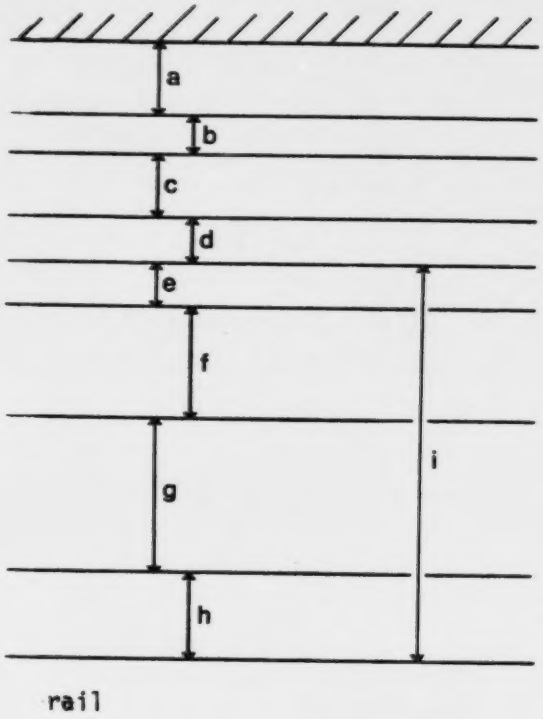
a. electrical clearance between catenary (dynamic position) and ceiling

b. uplift of catenary due to pantograph

c. messenger to contact wire distance (i.e. also catenary depth)

d. contact wire upward tolerance

e. contact wire downward tolerance



f. electrical clearance between contact wire and railcar

g. load gauge

h. track tolerance (also allows for future track uplift)

i. contact wire height

TABLE A-1 - Vertical clearances - mm

Source	A	B	C	D	E	F	G	H	I
A) BRITISH SYSTEM* OF POWER SUPPLY for 25 kV (normal clearances)	200	70	120	75	75	200	4015	25	4315
B) BRITISH SYSTEM OF POWER SUPPLY for 25 kV (reduced clearances)	150	50	120	10	10	150	4015	15	4190
C) BRITISH SYSTEM OF POWER SUPPLY for 25 kV (special reduced clearances)	70	25	120	10	10	125	4015	15	4165
2) AREA's standards for 50 kV	530	51	51	25	25	530	6400	300	7255
3) UIC's standards for 25 kV	170	100	-	-	-	290	-	20	-
4A) LA VOIE FERREE (French standards) 25 kV single wire catenary	270	-	N/A	30	30	240	4400	-	4640
4B) LA VOIE FERREE 25 kV simple catenary	270	-	300	25	25	240	4400	-	4690
5) INDIA's AC Traction Manual for 25 kV	270	-	-	20	20	270	-	-	5500
6) DANISH RAILWAY'S Extract of Project Manual for 25 kV	TOTAL CLEARANCE = 5650 mm								4950

* The British have adopted three classifications for vertical clearances at 25 kV.

3.3 ELECTRICAL CLEARANCES

In maintaining sufficient lateral clearance, the major concern is to prevent flashover from the pantograph to nearby structures. Figure A-2 illustrates the lateral components of pantograph sway. Table A2 lists the dimensions for each section based on the given sources. From this table, the following were observed:

(A) 200 mm for electrical clearance in the horizontal direction seems to be standard for 25 kV. It is doubled to 400 mm for 50 kV. There does not seem to be any logic to lateral clearance requirements being less than vertical ones. Neither should one justify them because they may be of an interim nature by virtue of a pantograph in motion. This is also some question as to the validity of doubling the clearance when the voltage is doubled since the breakdown of air dielectric is not directly proportionate to distance and voltage.

AIEE Standard No. 4, 1943 tabulates Sphere-gap Spark-over Crest Voltages versus variations in sphere gap spacing. Spark over occurs at less than double the voltage when spacing is doubled. It also varies with negative and positive crest voltages. For example when the sphere gap is increased from 2 cm to 4 cm, spark over occurs when the negative impulse crest is increased from 57 kV to 93.6 kV, i.e. 1.64 times the voltage. Therefore, if the voltage was doubled, it would appear that clearances should be more than double. Further laboratory measurements should be conducted.

(B) There is a wide variation in locomotive and pantograph tolerances. Further investigation should be done to determine if a more standardized figure can be calculated.

Further it does not seem reasonable to add all tolerances such as track tolerances, super elevation, locomotive car body rotation, pantograph rigidity, etc., algebraically to determine clearance requirements. It

is highly improbable that all the worst case conditions occur simultaneously.

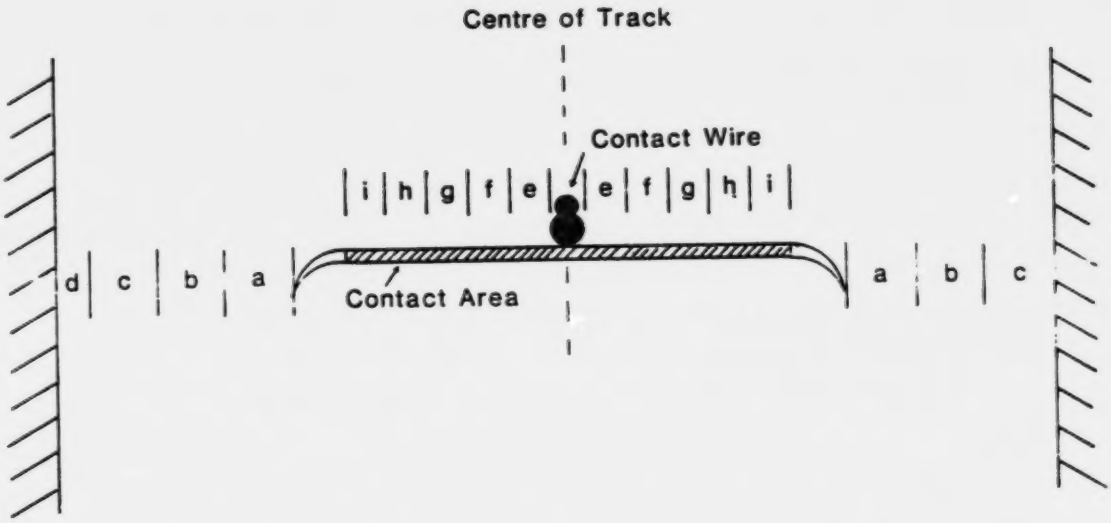
3.4 LATERAL CONTACT WIRE DISPLACEMENT

Lateral contact wire displacement refers to the deviation of the contact wire from the centre of track. The components of this motion are stagger, blow-off, construction tolerances and pole deflections. Stagger is a construction feature designed to give even wear on the pantograph. Construction tolerances are small deviations in positioning incurred when stringing the contact wire placing poles etc. Blow-off is the contact wire movement resulting from wind. Pole deflections result from loads applied to the pole (i.e. cantilever, wind).

The total displacement of the contact wire relative to the pantograph depends on both contact wire and pantograph displacements. Figure A-2b illustrates an example of contact wire displacement resulting from pantograph and contact wire movements in opposite directions. Under these conditions the possibility of a broken connection and arcing is raised.

Figure A-2a illustrates the components of contact wire displacement. It should be noted that the width of the contact area on the pantograph is shown as being wide enough for worst case conditions. As indicated in section 3.3.1, this may not represent a probable situation.

Figure A -2a
CONTACT WIRE DISPLACEMENT



a- electrical clearance

b- locomotive and pantograph tolerances

c- track tolerance

d- superelevation allowance

e- distance = b+c+d = pantograph displacement

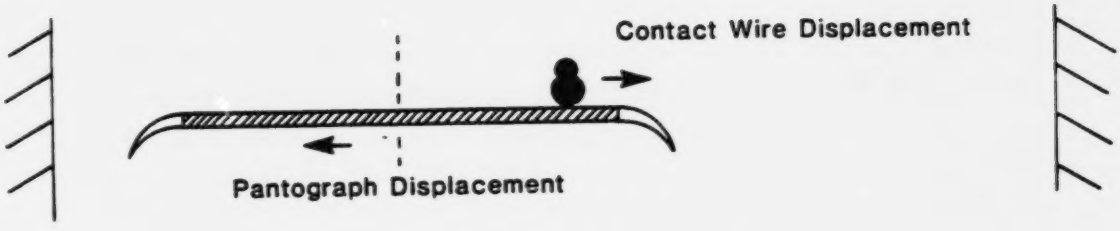
f- stagger

g- blow-off

h- construction tolerances

i- pole deflection

Figure A -2b
WORST CASE OF DISPLACEMENT



Worst Case for Contact Wire Displacement Equals e+f+g+h

Table A-2 - Lateral clearances - mm

Source	A	B	C	D	E	F	G	H	I
1) AREA's standards for 50 kV	400	605	25	800[1]	1530	-	-	-	-
2) UIC's standards for 25 kV	200	-	-	-	- 250[3]	200[2] or	-	-	-
3) BRITAIN's «Railway Construction and Operation Requirements»	400	130	-	-	-	-	-	-	-
4) INDIA's «AC Traction Model»	200	-	-	-	- 300[3]	200[2] or	-	-	-
5) ELECTRACK's design for Cartier Railway Study.	-	188	25	60	273	400	400	75	150

1 - for 150 mm of superelevation
2 - straight track
3 - tangent track

3.5 WEATHER LOADING

3.5.1 Thermal Loading

Heating of the catenary due to current flow and solar effects will result in expansion of the wire. Most catenary systems however employ constant tensioning devices to adjust for the added expansion. If the catenary exceeds its rated ampacity[1] though, the amount of longitudinal expansion may be greater than the capabilities of the constant tensioning units. As a result, the contact wire's sag will increase. Consequently, the current collection ability of the pantograph will decrease and a lower operating speed will have to be maintained.

A wire temperature of 80°C is considered the maximum value for copper wire before it starts to anneal. The current level at which the wire reaches 80°C will depend on ambient temperature, wind and solar effects.

3.5.2 Ice Loading

The added weight of ice and snow also increases contact wire sag. As mentioned, increased wire sag will place restrictions on locomotive operation.

Another major concern in ice loading is its effect on supporting structures. The additional moment will result in undesirable pole deflection. Contact wire deviation or, in the worst case, failure at the pole base could result.

ELECTRACK allows for 50.8 mm pole deflection and SJ 70 mm pole deflection at contact wire height with ice and wind loading in the CARTIER RAILWAY study. The Swedish standard SEN 3601 adopts the most liberal ice loads for power lines. In it, a radial ice coating of 18 mm is assumed with a density of .9 kg/m³. This corresponds to a load of ((.051)d - .92) kg/m where d. is the diameter of the wire. For a 100 mm² contact wire (12 mm diameter) the extra load is 15 N/m.

---

1 see AREA's «Manual for Railway Engineering», vol. II, p.33-4-1.

ELECTRACK however uses an ice coating of 12 mm (1/2 inch) and calculated a load of 9.9 N/meter in the Cartier Railway Study. The 12 mm figure is also used by Ontario Hydro and the CSA standard on overhead lines for heavy loading.

3.5.3 Wind Loading

The effects of wind on the catenary include:

(A) additional moments on poles and

(B) contact wire blow-off.

Contact wire blow-off is discussed in Section 3.4 - LATERAL CONTACT WIRE DISPLACEMENT. A wind speed of approximately 96 kmph (60 mph) is commonly used in determining the wind load. Ontario Hydro, CSA's and Sweden's standards for overhead lines, and ELECTRACK's proposal for CARTIER RAILWAY adopted this figure.

ELECTRACK translates a 96 kmph (60 mph) wind into a loading of 14 N/m. SJ's proposal for Cartier Railway study and Sweden's standards for overhead lines use 19.6 N/m for the same wind speed. It converts this figure to give a wind loading of 1 kN/m^2. CSA standard adopts a value of 385 N/m^2 for heavy loading.

4. CATENARY CONSTRUCTION

4.1 SPAN LENGTH

This term refers to the distance between adjacent supporting poles of the catenary system. Table A-3 provides a list of the distances employed by the various countries. 70 metres is the length commonly used for tangent track. The distance will reduce for curved track due to the additional radial load on the pole. The amount of reduction will depend on the degree of curvature. It is also the practice to reduce spans where high winds or tunnelling can cause greater blow-off.

4.2 CONTACT WIRE

4.2.1 Wear

Table A-3 indicates the acceptable amount of wear on the contact wire before replacement is necessary. Wear of 30% is the upper limit for a 107 mm^2 solid copper contact wire. For 25 to 50 kV 60 Hz systems, this usually requires contact wire replacement in around 50 years depending upon route traffic density.

4.2.2 Grade

Grade refers to the slope of the contact wire with respect to the rail. The grade is measured by the difference in height of the catenary of adjacent poles divided by the length between the poles. Too steep of a grade will result in excess contact wire wear. This is of special importance when approaching tunnels or overhead structures where lowering of the catenary may be necessitated.

Table A-3 - Catenary Parameters

Source	Radius of Curvature (m)	Pole Spacing (m)	Tension Section (m)	Tension (kN)
India's AC Traction Manual (25 kV)	Not given	72 (max)	1600 (with regulating equipment) 2000 (without regulating equipment)	Not given
B.C. Rail Study (50 kV)	Not given	70 (max)	1400	9.8
Britain's System of Electrical Power Supply for 25 kV AC Electrification	Not given	73 - 75 (max)	2000	11
SJ's Proposal for Cartier Railway		70 (max)	1400	9.8
Electrack's Proposal for Cartier Railway		73 (max)	1600 (max)	contact = 13 messenger = 20

4.3 TENSION

Table A-3 also records the tension in the contact and messenger wires as observed in the given reports. Between 9.8 and 11 kN is the tension most commonly adopted. In all designs, this is achieved through a common counter weight system.

Also shown are the tension sections lengths. A variation between 2000 and 1400 metres exists between the reports. It should be remembered that the figures given are maximum values and may be lowered in actual practice due to track curvature or railside terrain.

4.4 DISCONNECTS

To be determined

4.5 SECTION INSULATORS

To be determined

4.6 NEUTRAL SECTIONS

To be determined

5. POWER SUPPLY

5.1 SCOPE

This section is divided into two general categories. These are:
(A) Voltage supply to the locomotive
(B) Effects of a railway load on power utilities.

Each section gives a brief description of the practices employed. Further investigation will have to be made before a more detailed information base is obtained.

5.2 VOLTAGE SUPPLY

Table A-4 lists the voltage requirements established by the railways for locomotive operation. The range of performance is from +10% to -20% of nominal voltage.

Table A-4 - Voltage Regulation

Source	Maximum Voltage	Minimum Voltage	Minimum Instantaneous Voltage
1. Britain's System of Elect. Power Supply for 25 kV Ac Electrific.	25,750	24,250	-
2. UIC Standards (25 kV)	27,500	19,000	17,500
3. AREA Standards			
(a) 25 kV	27,500	20,000	17,500
(b) 50 kV	55,000	40,000	35,000
4. India's AC Traction Manual (25 kV)	27,500	23,750	-
5. B.C. Rail Study (50 kV)	55,000	40,000	37,500

5.3 ELECTRICAL LOADING

Three negative effects railways have on public utilities are:

(A) Voltage imbalance

(B) Phase (i.e. current) imbalance

(C) Harmonic current generation

The limits of each factor are often set by the individual utilities so a comprehensive figure could not be established. Table A-5 gives the restrictions set by India and Britain:

	INDIA	BRITAIN
Voltage Unbalance		
Instantaneous	5%	
2 hours	3%	3%
Continuous	2%	
Current Unbalance		
1 min.	45%	
10 min.	12%	
Continuous	8%	
Harmonic distortion		3%

Table A-5 - Voltage and Current Unbalance

These figures are indicative of the standards observed in most countries although France allows for a voltage unbalance as great as 7%.

6. EMI

6.1 SCOPE

The movement towards higher AC voltages will increase the coupling between the catenary and communication channels or the catenary and off-track metal structures (e.g. fences). In the first case, unacceptable interference levels may result. In the second case, a safety hazard may be created as high potentials are induced on the structures. The following forms of coupling were considered.

(A) Electromagnetic coupling
(B) Electrostatic coupling

In addition, a brief examination was made of the steps taken to limit their effect.

6.2 COUPLING

6.2.1 Electromagnetic

Alternating voltage is induced in railside circuitry by an alternating magnetic field set up by the contact wire current. The strength of the field is directly proportional to the value of current flowing. The magnitude of the induced voltage is a function of the circuits proximity to the field, the frequency of catenary current and the length of circuit parallel to the catenary.

Table A-6 gives the values used by some railways in establishing induced voltage limits.

Table A-5 - EMI Limits

	Induced Voltage
DANISH STATE RAILWAY	
(i) Signalling circuits	
@ 500 A (traction current)	150 V
@ 6000 A	650 V
(ii) communications circuits	
@ 500 A	60 V
@ 6000 A	450 V
CARTIER RAILWAY STUDY CALCULATED INDUCTION	
(i) fundamental - 320 A (traction current)	204 V/mile
3rd harmonic - 58 A	100 V/mile
5th harmonic - 26 A	71 V/mile
fault current - 1869 A	1193 V/mile
INDIA'S «AC TRACTION MANUAL»	
(i) underground signal cables	30 V/km
(if the parallel distance exceeds 4 km, a relay or other isolating device must be used)	120 V/maximum
French Standards from	
«LA VOIE FERREE»	30 mV/A/km
(i) cables are limited to 15 km of parallel length. This assumes a catenary current of 600 A. on 25 kV system.	(i.e. 270 V)

6.2.2 Electrostatic

Coupling in this case is accomplished by means of an «electric field» centered in the catenary. The metal structure, or circuitry and the catenary constitute a capacitor. The voltage induced on the structure will be a function of the catenary voltage and the structures distance from the catenary. A derivation in «LA VOIE FERREE» (pg. 449) has determined the voltage on the structure in terms of the distance between:

(A) Catenary and structure;
(B) Catenary and ground, and
(C) Structure and ground.

It also recommended that if the separation in metres between catenary and structure is of the order 1/6 UxL (U = catenary voltage, and L = length of parallelism in km), the effects of electrostatic induction may be neglected. The CARTIER RAILWAY study considers the danger of electrostatic induction a concern at voltages exceeding 100 kV. However, the study notes that at levels of 25 or 50 kV, small shocks may be induced by touching metal structures. This may lead to further unforeseen incidents. As a precaution, it therefore recommends grounding all metal structures. It should be noted that current need not flow for electrostatic coupling to exist.

6.3 MITIGATION TECHNIQUES

6.3.1 Grounding

Proper grounding techniques will reduce the hazard of electrostatic coupling and lower catenary impedance. This is primarily achieved through the use of a return wire mounted near the contact wire. Some catenary constructions also ground the poles. Additional bonding will also occur between:

(A) off-track metal structures and earth wire, and
(B) impedance bonds and earth wire.

The earth wire is divided into sections not exceeding 1000 m. The wire is to be grounded at mid-point to a 10 ohm (or less) earth. At each mast, the rail is bonded to the earth and mast on single rail track circuits. Off-track metal structures will be bonded either to the rail, an earth wire or a 10 ohm earth. The centre point of impedance bonds is connected to either return conductors or booster transformers. The use of a return wire will also lessen the effect of electromagnetic coupling. This is done as the field set up by the return current will tend to cancel that of the contact wire current. The amount of field weakening will depend on the return wire's proximity and current phase relationship with respect to the contact wire. Maximum effect occurs for close distances between the wires with the two currents in phase.

6.3.2 Booster Transformers

To maintain sufficient return current, 1:1 booster transformers are placed at various intervals of the order of 3 km in the catenary system. The primary winding is connected in series with the contact wire while the secondary winding is in series with the return conductor. Current flowing in the contact wire will thus cause current to flow in the earth wire. Booster transformers reduce the EMI from the contact wire but increase catenary impedance (i.e. additional voltage loss) and capital costs.

6.3.3 Cable Conditioning

This section lists some techniques which can be applied to parallel communication lines to reduce their susceptibility to EMI. These include:

(A) Movement of cables from EMI sources;
(B) twisting of conductors;
(C) shielding and coaxial shielded cables;
(D) fibre optics systems and
(E) radio systems.

The system adopted will depend on ease of implementation and capital costs. Use of shielded and coaxial cables will call for correct grounding of the metal shield. Care must be taken to prevent circulating ground currents. Separate earths are recommended for the shield.

6.3.4 Microwave Communications

The use of microwave for railway communications is based on the theory that interference from the catenary is reduced at high frequencies.

7. CATENARY IMPEDANCE

7.1 General

To be discussed/determined

7.2 SERIES CAPACITORS

To be discussed/determined

APPENDIX B

DETAILED STRENGTH CALCULATIONS

FOR SALVAGE RAIL POSTS

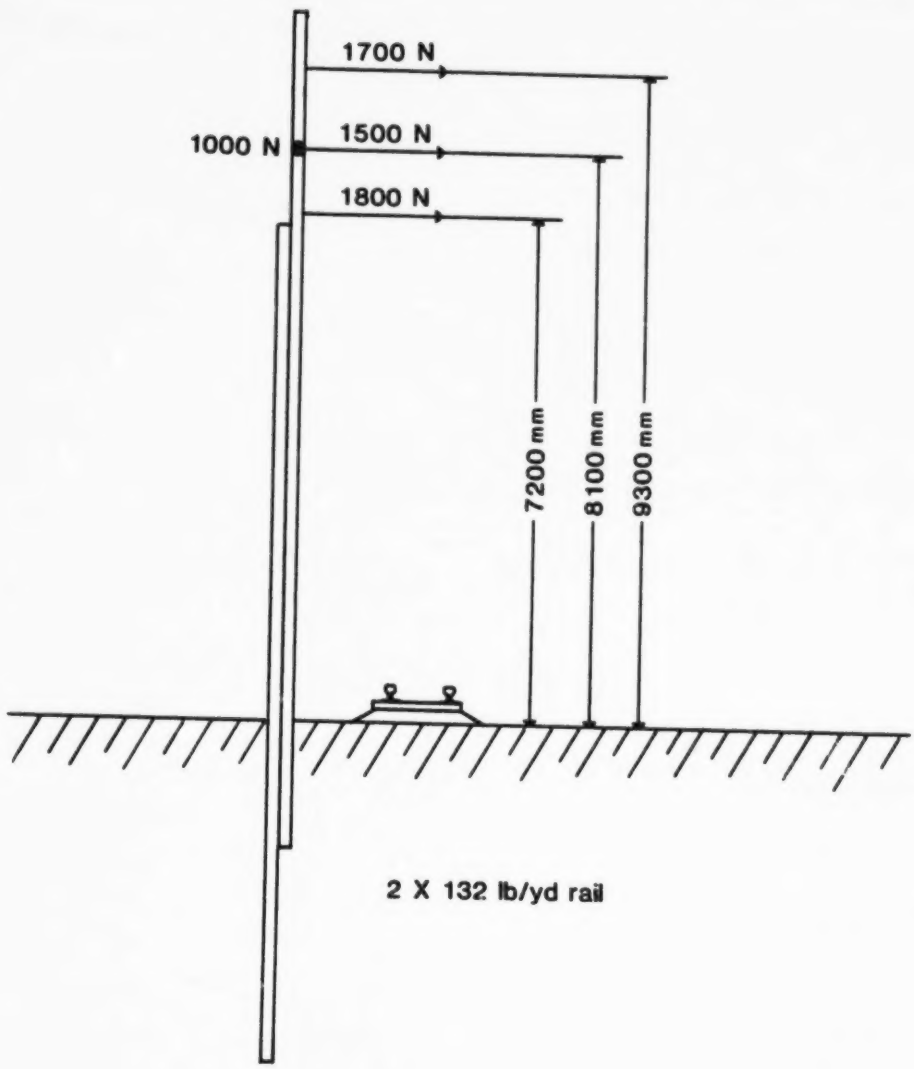


Figure B-1 - SALVAGE RAIL POST

The forces consist of dead and wind loads.

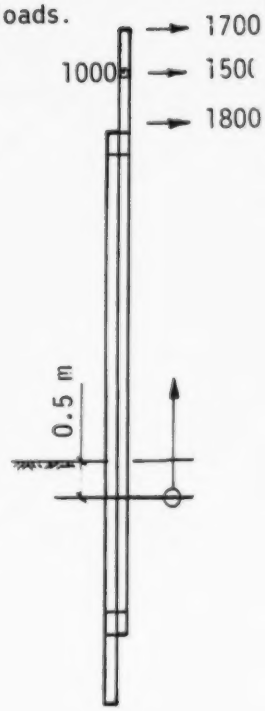
CASE 1: No cooperation between rails.

CATENARY POLE, made out of worn out rails

Design calculations

Forces in figure. The forces consist of dead loads and wind loads.

Assumption: no cooperation between rails.



Bending moments, stresses:

$M_{\perp} = 1700 \times 9.3 + 1500 \times 8.1 + 1800 \times 7.2 = 41{,}000$ Nm

$M_{\parallel} = 1000 \times 8.1 = 8100$ Nm

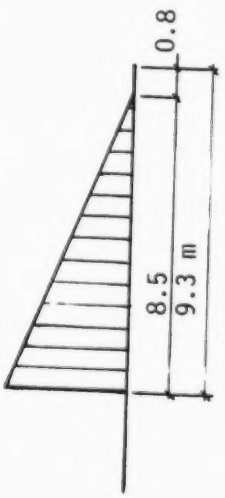
Section modulus, head 22.5 In^3

$$\sigma_{\perp} = \frac{M_{\perp}}{2\, W_{\perp}} = \frac{41{,}000 \times 10^3}{2 \times 22.5 \times 25.4^3} = 55 \text{ N/mm}^2$$

Section modulus, vertical axis (computer calculation based on simplified cross-section) 72,000 mm^3.

$$\sigma_{\parallel} = \frac{8{,}100 \times 10^3}{2 \times 72{,}000} = 56 \text{ N/mm}^2$$

$$\sigma_{res} = \sqrt{55^2 + 56^2} = 78 \text{ N/mm}^2$$



Deformation:

$$y = \int \frac{M}{EI}\, dx = \left[\frac{1}{EI} \frac{41{,}000 \times 8.3}{2} (0.8 + \frac{2 \times 9.5}{3})\right] =$$

$$= \frac{1.2 \times 10^6}{EI} = \frac{1.2 \times 10^6}{2 \times 210 \times 10^9 \times 88.2 \times 0.0254^4} =$$

$= 0.079$ m $= 79$ mm

Shear forces in bolted connections: (cooperation between rails)

$$\tau = \frac{TS}{Ib}$$

The middle connection obtain forces from a length L = 4.0 m

$T = 1700 + 1500 + 1800 = 5000$ N

$S = 12.95\ (88.2/22.5) = 50.8\ In^3$

$I = 2\left[88.2 + 12.95\ (88.2/22.5)^2\right] = 574\ In^4$

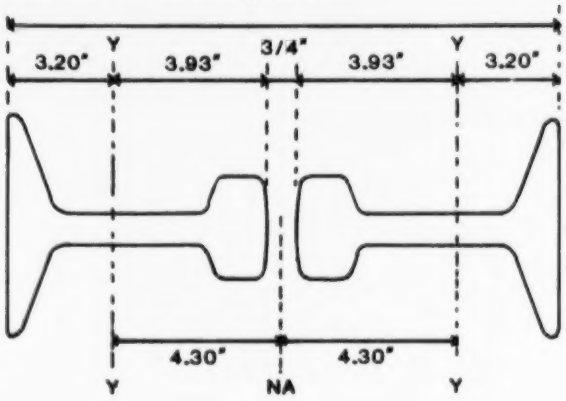
Maximum shear force: $T_b L = \frac{TS}{I} L =$

$$= \frac{5000 \times 50.8 \times 0.0254^3}{574 \times 0.0254^4} \times 4.0 =$$

$$= \frac{5000 \times 50.8}{574 \times 0.0254} \times 4.0 = 70{,}000\ N = 70\ kN$$

CASE 2: Rails connected crown to crown

Assume rails act together



$I_{combined} = 2 \times 88.2 + 2 \times 12.95 \times 4.30^2$

$= 655.3 \text{ in}^4$

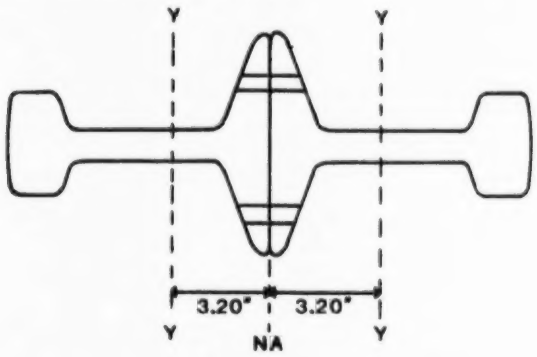
$I_{individual} = 2 \times 88.2 = 176.4 \text{ in}^4$

$Y_1 = \frac{I \text{ ind}}{I \text{com}} \cdot Yo = \frac{176.4}{655.3} .79 \text{ mm}$

$= 20.5 \text{ mm}$

CASE 3: Rails connected base to base

Assume rails act together



$I_{combined} = 2 \times 88.2 + 2 \times 12.95 \times 3.20^2$

$= 441.6 \text{ in}^4$

$Y_2 = \frac{I \text{ ind}}{I \text{ com}} \cdot Y_o = \frac{176.4}{441.6} \times 79 \text{ mm} = 31.6 \text{ mm}$

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LA COMPAGNIE MINIÈRE QUÉBEC CARTIER
PORT CARTIER, QUÉBEC, CANADA G5B 2H3

Le 26 avril 1982

L.C. TAIT
Canadian Pacific
Consulting Services Ltd
740, rue Notre Dame Ouest,
suite 760
Montréal, Québec

SUJET: Poteaux faits de vieux rails.
Electrification d'une section
de voie de la Compagnie de
chemin de fer Cartier.

Monsieur,

Tel que discuté par téléphone le 26 avril 1982, voici une estimation pour la fabrication de poteaux selon les plans numéros:1-502223-2 et 1-502223-3 de S J. Les poteaux seraient fabriqués et entreposés à Love.

Alternative No. 1:

	Matériel:	$462.
Main	d'oeuvre:	$457.
	TOTAL :	$919. par poteau

Alternative No. 2:

	Matériel:	$332.
Main	d'oeuvre:	$657.
	TOTAL :	$989. par poteau

Si vous désirez de plus amples informations, n'hésitez pas à me contacter.

Bernard Naud

Bernard Naud, ingénieur

BN/lp

Figure B-2: Copy of Cost Estimate for Salvage Rail Pole

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